

## Encapsulation of Pistachio Green Hull Phenolic Compounds by Spray Drying

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### ABSTRACT

Application of antioxidants is a common way for retarding oxidation. Due to adverse effects of synthetic antioxidants on health, the use of natural and safe antioxidants is considered essential. Pistachio green hull is a waste product and low-cost source of phenolic compounds. The use of phenolic compounds in food formulations has some limitations. In this study, the encapsulation of Pistachio Green Hull (PGH) phenolic compounds was carried out by spray-dryer using Maltodextrin (MD) as a wall material. For this purpose, the effective factors including the inlet temperature, dilution factor, wall:core ratio, and rate of feeding were optimized. MD, PGH extract powder, and encapsulated phenolic compounds produced under optimum conditions (ME) were characterized by Scanning Electron Microscopy (SEM), FTIR, X-ray Diffractometry (XRD), and Differential Scanning Calorimetry (DSC). Under optimum conditions, the amount of phenolic compounds and the encapsulation efficiency were 32.1 mg GAE g<sup>-1</sup> dp and 81%, respectively. DSC results showed that the microencapsulation had improved thermal stability of phenolic compounds. The DPPH test results indicated that the antioxidant activity of the free PGH extract was 10% higher than encapsulated one (ME). Storage stability results indicated that the amount of phenolic compounds of PGH extracts and ME after 60 days storage decreased by more than 29 and 4%, respectively. The microcapsules obtained can be used in the production of functional foods and pharmaceutical products, due to their antioxidant content and presence of phenolic compounds.

**Keywords:** Antioxidant activity, Functional foods, Maltodextrin, Polyphenols, Microencapsulation.

### INTRODUCTION

Pistachio Green Hull (PGH) is one of the rich sources of antioxidants, which also has antimicrobial activity. PGH extract contains many phenolic compounds (Goli *et al.*, 2005). Ghandehari Yazdi *et al.* (2019) reported that the main extracted phenolic compounds of PGH were gallic acid and phloroglucinol. PGH extract has been used as a good natural preservative in different food stuff (Abolhasani *et al.*, 2018).

The use of phenolic compounds in the formulation of functional food and pharmaceuticals is recommended for the

promotion of consumer health. However, phenolic compounds are susceptible to decomposition during process and storage due to the presence of oxygen, light, and high temperatures. Other limitations of direct applications of phenolic compounds in the formulation of food and pharmaceuticals are as follow: cause unpleasant taste, their low solubility, and interaction with food components. For this reason, the encapsulation of these compounds is an effective way to increase their physical stability, controlled release, and preventing them from the interaction with food ingredients, and increasing their functional

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properties (Ćujić-Nikolić *et al.*, 2019; Kuck and Noreña, 2016).

Researchers have reported the improvement of stability of the phenolic compounds extracted from many different natural sources during the storage by encapsulation (Saénz, *et al.*, 2009; Çam *et al.*, 2014). Among the several encapsulation techniques, spray drying is recommended because this technique is continuous, economical and flexible, and it is used as a method for preparation of flavors and food additives in food industries (Dalmoro *et al.*, 2012). In this technique, several factors such as inlet temperature, feed flow rate, and characteristics of the feed liquid are effective on the physicochemical properties of the powder produced (Tonon *et al.*, 2008). Therefore, optimizing the drying conditions is important to obtain products with better sensory and nutritional characteristics and better processing yield.

In the process of encapsulation, cellulose and various types of carbohydrates, gums, lipids, proteins and polymers are often used as a wall or carrier material. Among the available wall material, Maltodextrin (MD) is widely used due to high solubility in water, low viscosity, mild flavor, reasonable price, availability even at high concentrations, access to different molecular weights, and its colorless solutions (Ballesteros *et al.*, 2017).

In this study, Maltodextrin (MD, as a carrier) and spray drying method were used to encapsulate phenolic compounds of pistachio green hull extracts. The purposes of this research were as follow: (i) Optimization of effective factors of encapsulation by spray dryer (MD concentration, feed flow rate, inlet temperature, and dilution factor of PGH extract); (ii) To determine the antioxidant activity of free PGH extract and encapsulated PGH extract (ME); (iii) To investigate the stability of phenolic compounds of free PGH extract and encapsulated one (ME) during 60 days storage; and (iv) To evaluate the thermal

stability and morphological characteristics of the produced microcapsules.

## MATERIALS AND METHODS

### Plant Materials

Pistachio green hull (*Ahmadaghaei* variety), as a by-product of pistachio garden, was obtained from Yazd Agricultural Research Center (Yazd, Iran). It was dried and then ground and sieved through different meshes (18, 30, and 40) and was kept in a freezer at  $-20^{\circ}\text{C}$  until extraction.

### Chemical

Folin-Ciocalteu, 2,2-DiPhenyl-1-PicrylHydrazyl (DPPH), 2,2'-azino-bis (3 ethylbenzothiazoline- 6-sulphonic acid) diammonium salt (ABTS), potassium persulfate and maltodextrin (dextrose equivalent 13.0-17.0) from Sigma (St. Louis, MO, USA), 2, 4, 6-TriPyridyl-s-Triazine (TPTZ), acetic acid and methanol were obtained from Merck Chemical Co. (Darmstadt, Germany). Cellulase enzyme from Sigma (St. Louis, MO, USA), tannase enzyme from Kikkoman Biochemifa (Japan, Tokyo) and Pectinex BE color enzyme from Novozymes Ferment (Bagsvaerd, Denmark) were purchased.

### Enzymatic Extraction of Phenolic Compound from PGH

In this study, an enzymatic extraction method was used to increase the extraction yield of phenolic compounds from PGH. For this purpose, the combination of three enzymes, namely, pectinase, cellulase, and tannase was used according to the method and optimum conditions that were reported in our previous study (Ghandehari Yazdi *et al.*, 2019). The optimum parameters were used as follows: pectinase ( $3.8 \text{ U mL}^{-1}$ ), cellulase ( $2.5 \text{ U mL}^{-1}$ ), tannase ( $4.0 \text{ U g}^{-1}$ ),

time (4 hour), particle size ( $0.4 > \mu\text{m}$ ), solid to liquid ratio (1:80), pH= 4.5 and temperature ( $40^\circ\text{C}$ ).

### Preparation of the Microcapsules

The encapsulation was accomplished according to the method of Robert *et al.* (2010). Maltodextrin was heated to  $40^\circ\text{C}$ , and mixed with enzymatic extract (20 g) at constant stirring. The mixtures were homogenized by Ultraturax (IKA, T50, Germany) at  $1,400 \times \text{g}$  for 5 minutes and the mixtures were fed to a mini spray dryer (Buchi-220, Switzerland). Finally, the produced microcapsules were kept at  $-20^\circ\text{C}$  until the time of analyses. In this study, the effect of four variables, i.e. inlet temperature ( $140$ ,  $150$ , and  $160^\circ\text{C}$ ), wall:core ratio ( $0.5:1$ ,  $1:1$ ,  $2:1$ , and  $3:1$ ), feeding rate ( $7$ ,  $10$ , and  $13 \text{ mL min}^{-1}$ ) and extract dilution factor ( $0$ ,  $1.33$ , and  $2$  folds v/v) were evaluated to find optimum conditions using one-factor-at-a-time statistical method.

### Microcapsule Powder Analysis

#### Total Phenolic Contents

To investigate the total phenolic contents, the structure of the microcapsules was destructed. For this purpose,  $0.2 \text{ g}$  of microcapsules were added to  $2 \text{ mL}$  of methanol:acetic acid:water ( $50:8:42 \text{ v/v/v}$ ) and the dispersion was vortexed for 1 minute. After that, the dispersion was ultrasonicated (James, 6D, UK) for 40 minutes and, finally, the resultant dispersion was centrifuged at  $11,200 \times \text{g}$  for 5 minutes and then filtered through  $0.45 \mu\text{m}$  filter (Saéñz *et al.*, 2009; Robert *et al.*, 2010). The concentrations of phenolic compounds of microcapsules were quantified according to the Folin-Ciocalteu method (Slinkard and Singelton, 1977). The concentration of phenolic compounds was calculated according to the standard curve of gallic acid ( $Y = 0.0013x - 0.00553$ ;  $r = 0.9955$ ) and reported in milligrams of Gallic Acid

Equivalent per gram of dry powder (dp) ( $\text{mg GAE g}^{-1} \text{ dp}$ ).

### Surface Phenolic Compounds

To determine surface phenolic compounds,  $0.2 \text{ g}$  of microcapsules were added to  $2 \text{ mL}$  of methanol:ethanol ( $1:1 \text{ v/v}$ ) and the dispersion was vortexed for 1 minute. Then, the dispersion was filtered through a  $0.45 \mu\text{m}$  filter. The concentrations of surface phenolic compounds were determined according to the Folin-Ciocalteu method, which was previously described. The Surface phenolic compound percentage (SB), and the Encapsulation Efficiency (EE%) (Robert *et al.*, 2010), were calculated according to the following formulas:

$$\text{SB (\%)} = \frac{\text{SPC}}{\text{TPC}} \times 100$$

$$\text{EE (\%)} = 100 - \text{SB}$$

SPC= Surface phenolic compounds

TPC= Total phenolic compounds

### Physicochemical Characterization of Microcapsules

#### Scanning Electron Microscopy (SEM)

The morphology of microcapsules was studied by Scanning Electron Microscopy (Phenom, Pro X, Netherlands) at  $15 \text{ kV}$  with a magnification range of  $500-5,000$ . Powders were mounted to SEM aluminum stubs via a 2-sided adhesive tape and they were coated with a thin layer of gold before imaging.

#### Differential Scanning Calorimetry (DSC)

The glass transition temperatures of the MD, PGH extract powder (dried with spray dryer), and ME were accomplished by DSC (Netzsch-DSC 200F3, Germany). Each sample ( $8 \text{ mg}$ ) was placed in standard aluminum crucibles and an empty crucible



was used as a reference. The measurements were carried out between 10 and 300°C at a heating rate of 5°C min<sup>-1</sup>, under a nitrogen flow rate of 100 mL min<sup>-1</sup>.

### X-Ray Diffractometry (XRD)

Diffractograms of the MD, PGH extract powder and ME were obtained by X-ray diffractometer (XRD, X'Pert MPD, Philips, Netherlands). X-ray source was CuK $\alpha$  radiation ( $\lambda = 1.54056 \text{ \AA}$ ) with 40kV and a 30mA current, measured and scanned in the 2 $\theta$  angle range between 10 and 80° with a scan rate of 8° min<sup>-1</sup>, and a step size of 0.02°.

### FTIR

Functional groups and bonding arrangement of existing components in the samples were investigated by infrared spectroscopy in the region from 4,000 to 400 cm<sup>-1</sup>, by a FTIR spectrometer (Nicolet, USA).

### Antioxidant Activity

Antioxidant activity of free PGH extracts and Microencapsulated PGH Extracts (ME) were evaluated by DPPH<sup>•</sup> assay. DPPH radical-scavenging activity was determined according to the method of Hatano *et al.* (1988).

### Storage Stability of Produced Microcapsules

The stability of ME was accomplished by Aliakbarian *et al.* (2018) with some modifications. Free PGH extract (control) and produced ME were stored at room temperature (25°C) and at the light protected for 60 days. The amounts of phenolic compounds were determined on the first, 20<sup>th</sup>, 40<sup>th</sup>, and 60<sup>th</sup> days.

### Statistical Analysis

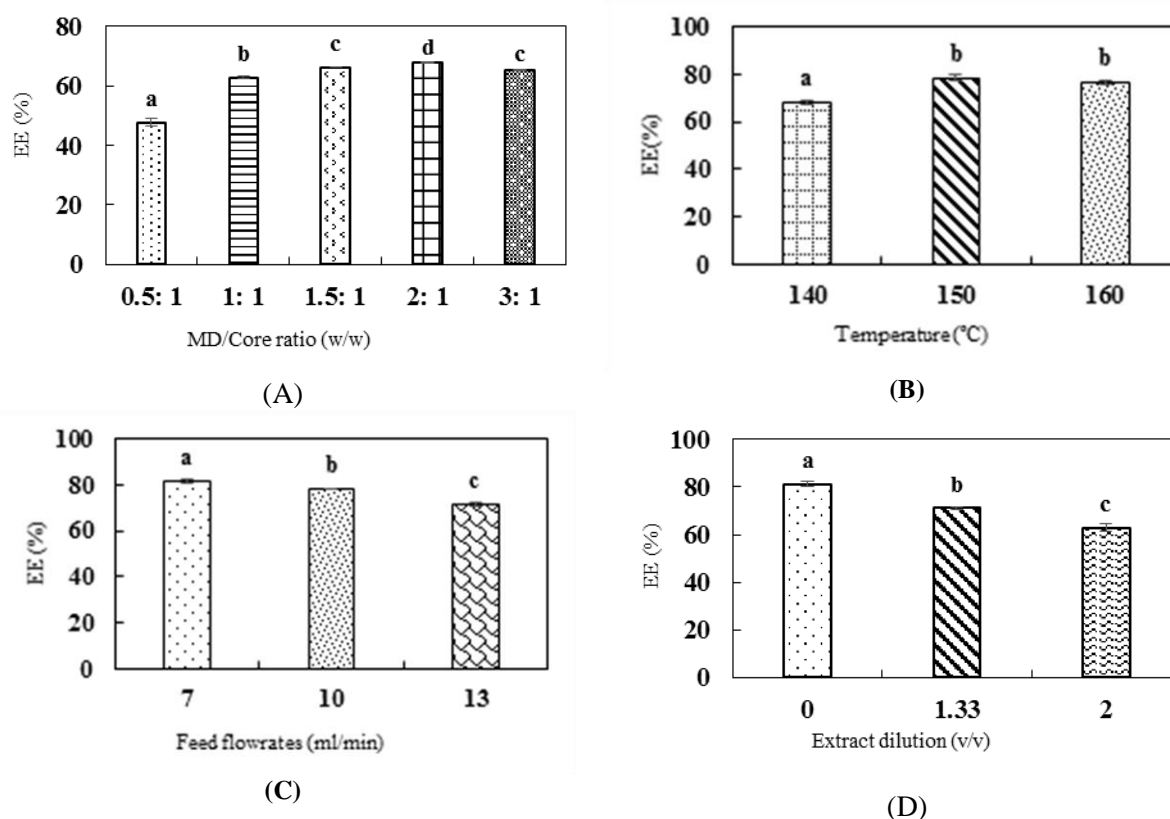
All experiments were done in triplicate. Results were reported as the average value  $\pm$  standard deviation and considered significantly different when  $P < 0.05$ . Statistical analysis was done using SAS software program version 9. Analysis Of Variance (ANOVA) and LSD test was applied to characterize the significant differences between different treatments.

## RESULTS AND DISCUSSION

### Effects of MD:Core Ratio on EE%

At first, to optimize the MD:Core ratio, all factors were considered constant (extract dilution factor 0 v/v, feeding rate 10 mL min<sup>-1</sup> and inlet temperature 140°C). The effect of MD:Core ratio on the EE% of phenolic compounds was evaluated at five levels (0.5:1, 1:1, 1.5:1, 2:1, and 3:1 w/w). Obtained results showed that by increasing the MD:Core ratio from 0.5:1 to 2:1, the EE% increased about 1.5 times, then, the EE% decreased significantly (Figure 1A). Different wall:core ratios have been reported by various researchers (Saénzet *et al.*, 2009; Robert *et al.*, 2010; Çam *et al.*, 2014; Aliakbarian *et al.*, 2018).

According to the reported results, probably, by increasing the wall:core ratio, viscosity increases, and this leads to a decrease in the movement of phenolic compounds to the surface. Çam *et al.* (2014) mentioned that the increment of the MD to phenolic compounds ratio increases the stability of phenolic compounds. Young *et al.* (1993) suggested that increasing the concentration of wall materials increased the encapsulation efficiency, which can be related to the effect of wall materials concentration on the formation of surface core prior to the formation of crust around the drying droplets. Based on our results, the MD:Core ratio of 2:1 w/w was selected as an optimum ratio for encapsulation of PGH phenolic compounds.



**Figure 1.** Effect of Maltodextrin (MD):Core ratio (A), inlet temperature (B), feed flow rates (C), and extract dilution (D) on the Encapsulation Efficiency (EE%) of phenolic compounds of Pistachio Green Hull extracts (PGH).

### Effect of Inlet Temperature on EE%

Effect of inlet temperature (140, 150 and 160°C) on the EE% of PGH phenolic compounds were studied at constant conditions (extract dilution factor 0 v/v, feeding rate 10 mL min<sup>-1</sup> and MD:Core ratio= 2:1). According to the Figure 1B, increasing the temperature from 140 to 150 °C increased the EE% of phenolic compounds of PGH by 15% and then remained constant ( $P < 0.05$ ). Similar results have been published by others (Kaderides *et al.*, 2015). In contrast, Saénzet *et al.* (2009) reported that the temperature had no significant effect on the EE% of bioactive compounds from cactus pear. As a result, microcapsule drying rate depends on inlet temperature and higher drying air

temperatures accelerated the fast formation of a firm membrane on the droplet surface, giving optimum core material retention (Kaderides *et al.*, 2015). In this study, the amount of phenolic compounds in the powder obtained at temperatures of 140, 150 and 160°C was 123.5, 147.5 and 118.0 mg GAE g<sup>-1</sup> dp, respectively. These results showed that drying temperature had influence on the amount of phenolic compounds. Similar results were reported by Sablania and Bosco (2018). Also, Podsedek (2007) suggested that phenolic compounds are sensitive to heat; but the finding of Robert *et al.* (2010) and Çam *et al.* (2014) indicated that the drying temperature did not affect the amount of phenolic compounds. In addition to the mentioned points, by increasing the temperature, evaporation was also increased and excessive evaporation caused fissures and deformations in the wall materials, causing premature release of their



contents and degradation of the encapsulated ingredient (Ramírez *et al.*, 2015). Increasing the amount of phenolic compounds at 150°C could be related to the hydrolysis of PGH polyphenols conjugated during the preparation of the samples or during the drying process (Turkmen *et al.*, 2005). According to our results, the inlet temperature of 150°C was chosen for encapsulation of PGH phenolic compounds.

#### Effects of Feed Flow Rates on EE%

The effect of different feed flow rates (7, 10 and, 13 mL min<sup>-1</sup>) at constant conditions (extract dilution factor 0 v/v, Inlet temperature: 150°C and MD:Core ratio= 2:1 w/w) was studied on the EE%. Increasing the feed flow rates from 7 to 13 mL min<sup>-1</sup> decreased EE% of phenolic compounds by about 10% (Figure 1-C). This effect has been observed by other researchers (Tonon *et al.*, 2008; Murugesan and Orsat, 2011). Contrary to these results, Paini *et al.* (2015) indicated that the feed flow rates did not affect the EE% of olive pomace. The negative effects of increasing feed flow rates on the EE% could be a consequence of slower heat and mass transfer and also the amount of the blend passed straight to the chamber and was not atomized (Tonon *et al.*, 2008). Therefore, 7 mL min<sup>-1</sup> was selected as optimum feed flow rate.

#### Effects of the Dilution Factor of Extract on EE%

The effect of different dilution factors of extract (0, 1.33 and 2 folds v/v) at constant conditions (Inlet temperature: 150°C, rate of feeding 7 mL min<sup>-1</sup> and MD:Core ratio= 2:1) on the EE% of PGH phenolic compounds was also evaluated. Increasing the dilution factor from 0 to 2 v/v decreased the EE% of phenolic compounds about 19% (Figure 1-D). Tumbas Šaponjac *et al.* (2016) reported that beetroot pomace extract without dilution in soy protein was suitable for obtaining the

highest encapsulation efficiency (86.14%). The reason for these results could be attributed to the dextrin's starch properties. In this type of starch, in addition to  $\alpha$ -(1→4)-linkages and  $\alpha$ -(1→6)-linkages, new linkages may be created and provide conditions to increase the reduction of glucose with other compounds (core). Thus, by increasing the amount of the PGH extract, a greater amount of the extract can be bonded to maltodextrin. According to the results, extraction without dilution was used for encapsulation.

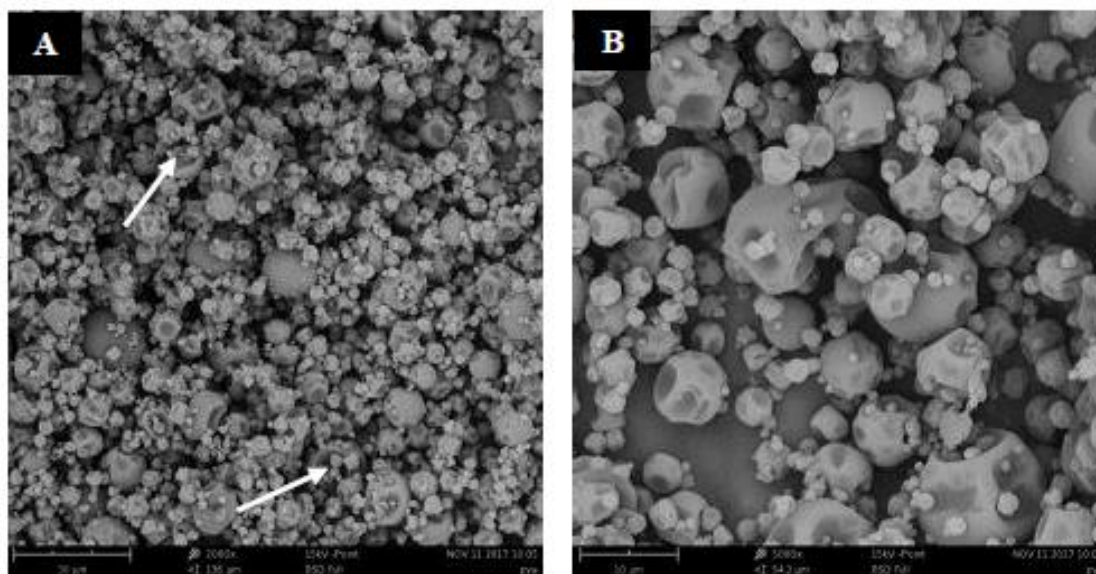
Spray drying under optimum conditions, i.e., Extract dilution: 0 v/v, Feed flow rates: 7 mL min<sup>-1</sup>, MD:Core ratio= 2:1 w/w and inlet temperature of 150 °C, resulted in the highest EE% (81%) and with high polyphenols content (32.1 mg GAE g<sup>-1</sup> dp).

#### Morphology

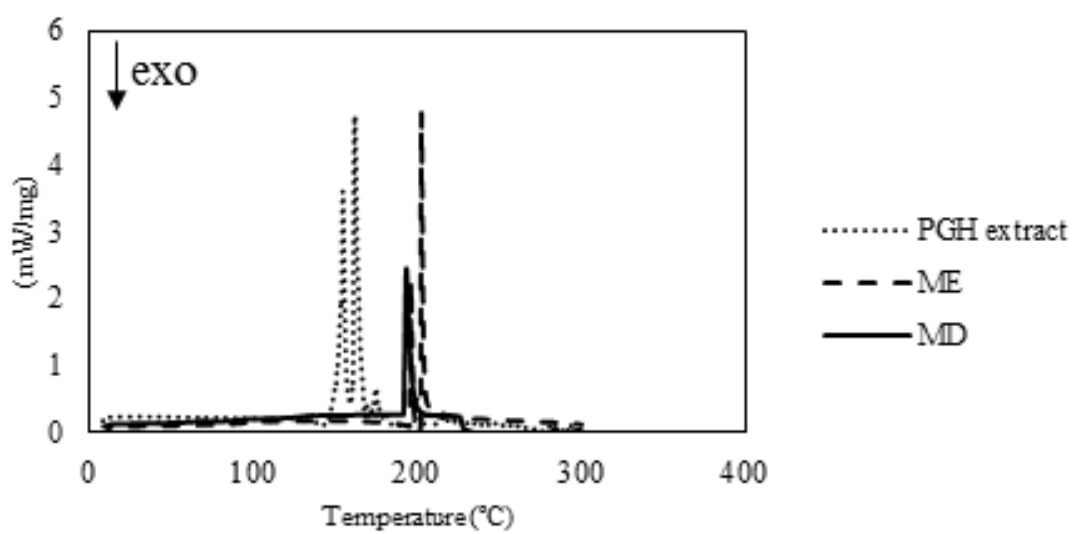
The morphological characteristics of Microencapsulated PGH Extracts (ME) are presented in Figure 2. The particles of MD were spherical with dented surface and amorphous structures. Similar observations of morphology have been reported by Robert *et al.* (2010). Indentation on the surface could be a consequence of the shrinkage of the maltodextrin particles during the drying process (Robert *et al.*, 2010). It can be seen that some ME have been damaged (arrows in Figure 2-A). Same results were reported by Aliakbarian *et al.* (2018). The structure of amorphous microcapsules increases their spreadability and solubility properties in food products, in order to improve the functional properties of food (Robert *et al.*, 2010).

#### DSC Analysis

The PGH dry extract showed two significant endothermic peaks at 154 and 162°C and several endothermic peaks in a range of temperatures between 165 and 300°C, related to the melting point of the



**Figure 2.** Scanning electron microscopy images of Microencapsulated pistachio green hull Extracts (ME): (A)  $\times 2000$ , (B)  $\times 5000$ .



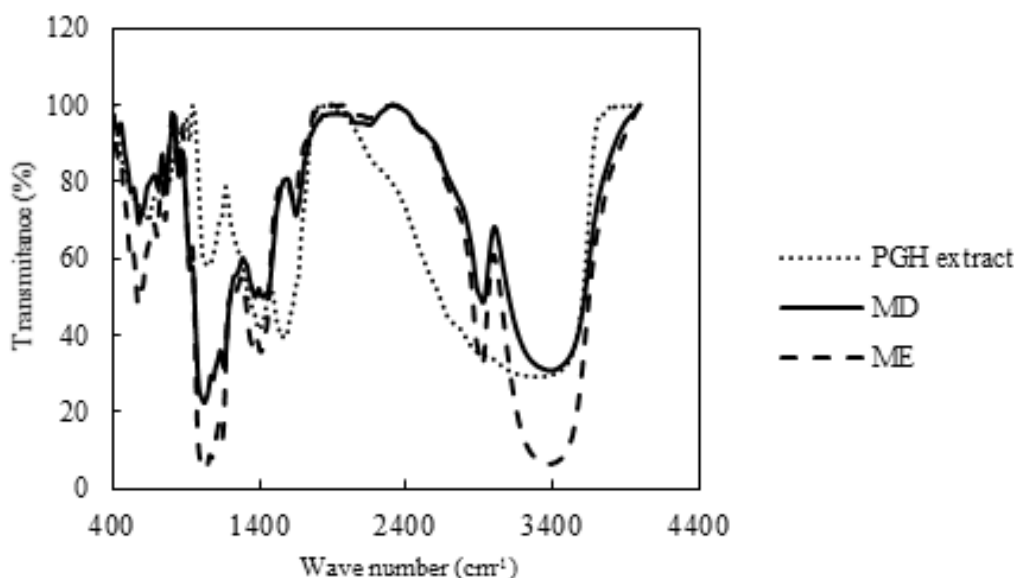
**Figure 3.** DSC thermograms of free Pistachio Green Hull extracts powder (PGH), Maltodextrin (MD), and Microencapsulated pistachio green hull Extracts (ME).

active compounds, mainly phenolic compounds (Figure 3) (Sansone *et al.*, 2011). An endothermic peak observed at 193°C for MD was related to the thermal degradation of MD. Due to the variable dextrose equivalents of maltodextrin, its melting point and degradation can be different. Souza *et al.* (2017) reported the melting point and beginning of thermal degradation of maltodextrin at 211°C. According to Figure 3, two endothermal peaks were observed at temperatures of 196 and 202°C for ME. The absence of the peaks of the PGH dry extract in the thermal profiles of ME confirmed that PGH extract was well encapsulated within MD, as previously revealed by SEM, and thermal stability increased. Similar results have been reported in relation to the increase of thermal stability of bioactive compounds by encapsulation. Ballesteros *et al.* (2017) indicated that thermal stability of phenolic compounds extracted from coffee ground improved by maltodextrin and gum Arabic about > 190°C and > 225°C, respectively. Negrão-Murakami *et al.* (2017) reported that maltodextrin (Dextrose equivalent= 10.2) enhanced thermal stability of the mate

microcapsules to 184°C. The presence of new peak (at 202°C) suggested that chemical interactions occurred between MD and PGH (Naidu *et al.*, 2004). Due to the high thermal stability of ME and the typical food industry sterilization temperature. It can be concluded that ME can be used to enhance the functional qualities of food.

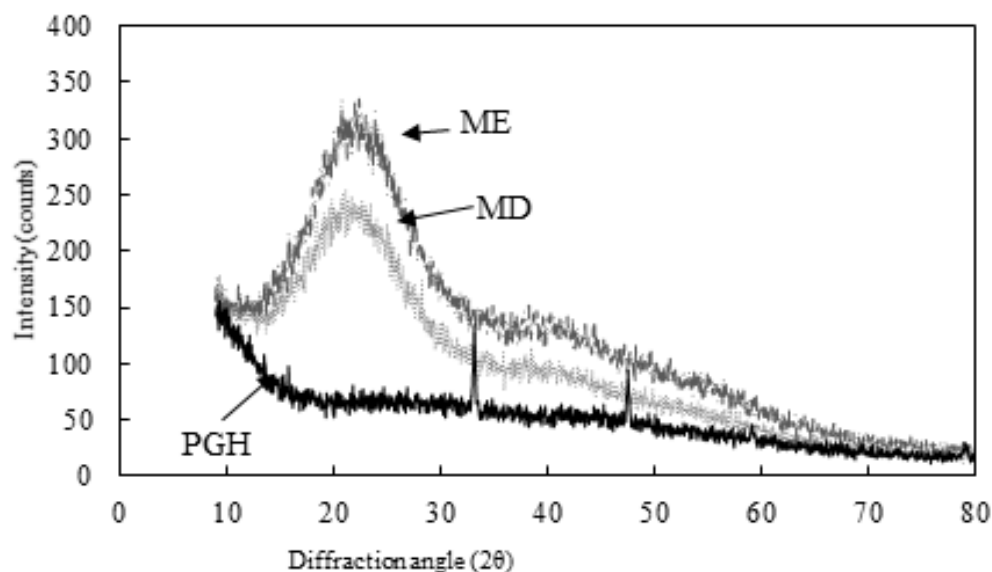
### FTIR Spectroscopy

The FTIR spectra of MD, PGH dry extract and ME are presented in Figure 4. The FTIR spectrum of MD indicated a strong and broad band at 3,398.94  $\text{cm}^{-1}$  which is attributed to the stretching vibrations of OH, 2,926.84  $\text{cm}^{-1}$  to C–H stretching vibrations, 1,648.77  $\text{cm}^{-1}$  to C=O stretching, 1,424.29  $\text{cm}^{-1}$  to C–H vibration, 1,371.90  $\text{cm}^{-1}$  to O–H bending, 1,156.31 and 1,082.36  $\text{cm}^{-1}$  to C–O stretching, 930.56  $\text{cm}^{-1}$  related to the deformation of the =CH and =CH<sub>2</sub> bonds and 850.81 and 762.52  $\text{cm}^{-1}$  to C–H bending and ring puckering. Yingngam *et al.* (2018) observed similar spectra for maltodextrin. FTIR spectra of PGH dry extract (Figure 4) indicated several peaks at 3,308.81  $\text{cm}^{-1}$  (OH



**Figure 4.** IR spectra of free Pistachio Green Hull extracts powder (PGH), Maltodextrin (MD) and Microencapsulated pistachio green hull Extracts (ME).



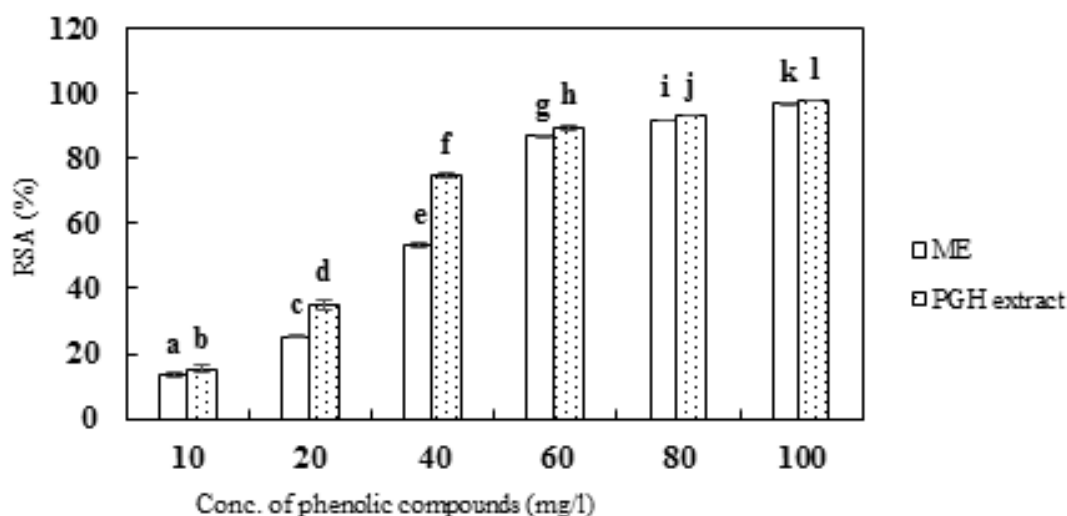


**Figure 5.** The X-Ray diffractograms of free Pistachio Green Hull extracts powder (PGH), Maltodextrin (MD) and Microencapsulated pistachio green hull Extracts (ME).

stretching band of phenolic and hydroxyl groups),  $1585.41\text{ cm}^{-1}$  (C=C relates to the vibration stretching band of aromatic rings),  $1,405.96$  and  $1,402.80$  ( $\text{CH}_3$  bending) and  $927.09$  and  $651.09$  (CH bending). Rafiee *et al.* (2017) observed prominent absorption bands at  $3,419$ ,  $1,719$ ,  $1,650$ ,  $1,508$ ,  $1,357$ ,  $1,203$ ,  $1,074$  and  $1,029\text{ cm}^{-1}$  for PGH dry extract. Bands in the range of  $1700$  and  $900\text{ cm}^{-1}$  could be assigned to the bands of PGH phenolic compounds (Yingngam *et al.*, 2018) and also the existence of carboxylic acids and sugars were confirmed by the spectrum obtained at  $1430\text{-}1330\text{ cm}^{-1}$  (Fragoso *et al.*, 2011). The FTIR spectrum of ME was almost like the spectrum of pure maltodextrin and the PGH bands were almost covered by MD bands. According to Figure 4, the intensity of the peak of the ME was higher compared with that of the PGH and MD and also the absence of peak at  $1585.41\text{ cm}^{-1}$  in the spectrum of ME compared with the spectrum of PGH indicated that there might be some interactions between PGH extract and MD.

### X-Ray Diffractometry (XRD)

X-Ray Diffractogram's patterns with broad bands showed amorphous structures because the molecules in the amorphous state are disordered and thus yield dispersed bands, while crystalline materials yield sharp and defined peaks since they are presented in a highly ordered state (Caparino *et al.*, 2012). As seen in Figure 5, the presence of sharp peaks at the diffraction angles ( $2\theta$ ) of  $33.17$ ,  $47.54$  and  $59.15^\circ$  showed semi crystalline structure of PGH dry extracted. The diffraction pattern of MD and ME showed completely amorphous structure, without intense and sharp peaks. Similar diffraction pattern has been observed for MD by Ballesteros *et al.* (2017). The differences between XRD profiles of the ME and PGH dry extracted indicate that the PGH extract was encapsulated in the MD. Due to the maltodextrin amorphous structure, the microcapsules' structure was also non-crystalline; this result could be



**Figure 6.** Antioxidant activity of free Pistachio Green Hull extracts powder (PGH) and Microencapsulated pistachio green hull Extracts (ME).

related to the point that PGH extract was spread at the molecular level in the maltodextrin matrix (Desai and Park, 2005). These outcomes confirmed the results of the SEM morphologies, which showed the structure of amorphous ME. Our results agree with reports of Ballesteros *et al.* (2017) and Tao *et al.* (2017).

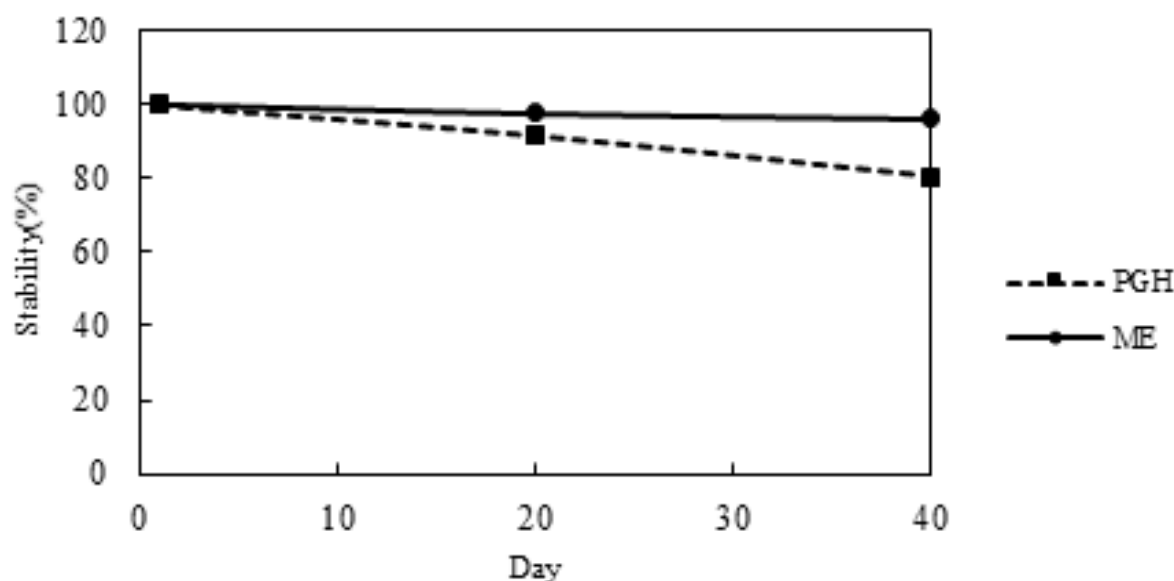
### Antioxidant Activity

Figure 6 indicates the antioxidant activity of free PGH extract and microencapsulated one (ME). As seen, there is a direct and positive correlation between the amount of PGH extract and ME and their DPPH radical scavenging ability. Increasing the radical scavenging capacity could be related to the number of hydroxyl groups in the reaction medium. In fact, the probability of hydrogen donation to free radicals increases by increasing the total phenolic content (Pyo *et al.*, 2004). Encapsulation of PGH extract significantly decreased the radical scavenging capacity ( $EC_{50} = 27.46 \text{ mg L}^{-1}$ ), which was about 10% lower than that of the free PGH extract ( $EC_{50} = 37.64 \text{ mg L}^{-1}$ ). Reduction of the antioxidant activity of ME might be consequence of the interactions

between PGH extract and MD, which has been confirmed by previous tests (DSC, FTIR, and XRD).

### Storage Stability

The stabilities of the phenolic compounds of free PGH extract and ME are shown in Figure 7. According to the results, the stability of the Microencapsulated PGH Extract (ME) is more than the free PGH extracts. The amount of phenolic compounds of free PGH extracts and ME, after 60 days storage, decreased by more than 29 and 4%, respectively. Çam *et al.* (2014) showed that microcapsules containing phenolic compounds of pomegranate peels were stable at 4°C for 90 days. Also, Paini *et al.* (2015) indicated that microcapsules covering phenolic compounds of olive pomace were stable up to 28 days at 25 °C. The results can be related to the protective role of the wall material against oxidation (Çam *et al.*, 2014) and the degree of susceptibility may affect the oxidation stability of phenolic compounds, which differs in stability during storage. Robert *et al.* (2010) and Murugesan and Orsat (2011) showed that maltodextrin, as one of the best



**Figure 7.** Storage stability of phenolic compounds of free Pistachio Green Hull extracts powder (PGH) and Microencapsulated pistachio green hull Extracts (ME)

wall materials, increased the stability of phenolic compounds during the storage.

## CONCLUSIONS

Utilization of pistachio green hull as a source of phenolic compounds in food industry is recommended. Pistachio green hull extract was successfully encapsulated in maltodextrin by spray drying for the first time. This study showed that feed flow rate, wall to core ratio, dilution factor, and inlet temperature were effective on encapsulation efficiency, and under optimum conditions (Extract dilution: 0 v/v, Feed flow rates: 7 mL min<sup>-1</sup>, MD:Core ratio= 2:1 w/w and inlet temperature of 150°C), the efficiency of encapsulation and the amount of phenolic compounds were 81% and 32.1 mg GAE g<sup>-1</sup> dp, respectively. The encapsulation was proved by SEM, FTIR, XRD and DSC. Additionally, this showed that thermal stability of phenolic compounds extracted from pistachio green hull was improved by encapsulation.

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### پوشینه سازی ترکیبات فنولی پوست سبز پسته با خشک کن پاششی

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### چکیده

یکی از راه‌های متداول تأخیر در اکسایش استفاده از ضداکساینده‌ها است. به دلیل اثرات نامطلوب ضداکساینده‌های سنتزی بر سلامت مصرف‌کنندگان، به کارگیری ضداکساینده‌های طبیعی و ایمن



ضروری به نظر می‌رسد. پوست سبز پسته یکی از ضایعات فرآورده‌های کشاورزی و منبع ارزان‌قیمت ترکیبات فنولی است. استفاده از ترکیبات فنولی در فرمولاسیون مواد غذایی دارای محدودیت‌هایی است. در این مطالعه، پوشینه سازی ترکیبات فنولی پوست سبز پسته به روش خشک‌کن پاششی و توسط مالتودکستروزین، به‌عنوان دیواره، انجام شد. بدین منظور، فاکتورهای مؤثر در پوشینه سازی شامل دمای ورودی، فاکتور رقت، نسبت دیواره:هسته و سرعت خوراکی‌دهی بهینه‌سازی شدند. خصوصیات مالتودکستروزین، پودر عصاره آبی پوست سبز پسته و ریز پوشینه‌های حاوی عصاره آبی پوست سبز پسته توسط میکروسکوپ الکترونی روبشی (SEM)، FTIR، پراکنش اشعه ایکس (XRD) و گرماسنجی روبشی تفاضلی (DSC) بررسی شدند. تحت شرایط بهینه، مقدار ترکیبات فنولی و کارایی پوشینه سازی به ترتیب ۳۲/۱ mg GAE/g dp و ۸۱ درصد بود. نتایج DSC نشان داد که ریز پوشینه سازی پایداری حرارتی ترکیبات فنولی را بهبود بخشیده است. نتایج آزمون DPPH مشخص نمود که فعالیت ضد اکسایشی عصاره آزاد پوست سبز پسته ۱۰ درصد بیشتر از عصاره ریز پوشینه شده است. نتایج بررسی پایداری ترکیبات فنولی عصاره آزاد و ریز پوشینه شده طی ۶۰ روز نگهداری مشخص کرد که پایداری آن‌ها به ترتیب ۲۹ و ۴ درصد کاهش یافته است. ریز کپسول‌های به‌دست آمده به دلیل وجود ترکیبات فنولی در آن‌ها و خاصیت ضد اکسایشی که دارند می‌توانند برای تولید غذاهای فراسودمند و فرآورده‌های دارویی به کار برده شوند.